AN EARLY HISTORY OF LOWER LIMB AMPUTATIONS AND PROSTHESES

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The first amputation was performed sometime far back in prehistory, likely by someone pressed into service before medicine was even an established craft. We have evidence of Neolithic amputations of fingers, indicated by outlines of hands drawn on cave walls in France and Spain. These have been dated to about 5000 B.C.[4] Many of these amputations were probably ritualistic, but other possible reasons include trauma, frostbite, leprosy, and Raynaud's phenomenon. Many skeletal remains have been found in different areas of the world with amputated hands and arms. In the Middle East, the most common reason for amputation was punishment for crimes. Because of this, some patients refused amputation for medical reasons because it would identify them with criminals. Those who lost limbs to frostbite often carried certificates stating the reason for their loss of limb.[4]

Many early peoples did not practice amputation, even to save a life, because they believed that to amputate meant to deprive the person of the extremity both in this life and the next. Most preferred to die with the diseased limb intact, particularly the lower extremity. Amputations of hands were sometimes done as a means of verifying numbers of prisoners taken in battle.[4] However, amputation of a foot or leg was less frequent since it rendered the captive unfit to work. Lower limb amputation remained a severe form of punishment, or for dire medical emergency.[4] In Peru, amputated feet date from about 300 B.C. onward.[4] Herodotus, in his *History,* written in 484 B.C., tells of a Persian soldier, Hegesistratus, captured by the enemy, imprisoned in the stocks, and encased by his foot. He escaped by cutting off part of his foot, and replaced it later with a wooden prosthesis.[18] A mosaic from the Cathedral of Lescar, France, probably from the Gallo-Roman era, depicts an amputee supported by a wooden pylon (Figure 1). A fragment of an ancient vase unearthed near Paris in 1862 shows an amputee whose limb has been replaced by a pylon with a forked end (Figure 2).[18] Peruvian figurines from the first and second centuries A.D. depict amputees, with one figure from about 50 B.C. showing the amputee placing a crude cup-like prosthesis on his stump (Figure 3).

Figure 1. Mosaic from Gallo Roman era from Cathedral of Lescar, France. (Reprinted from Atlas of Limb Prosthetics, C.V. Mosby, 1980).

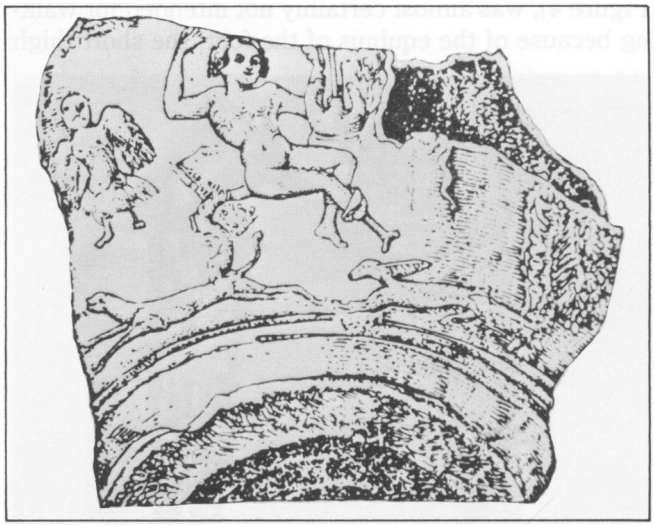

Figure 2. Fragment of vase showing amputee with pylon. (Reprinted from Atlas of Limb Prosthetics, C.V. Mosby, 1980).

The oldest recovered prosthesis, found in a tomb in Capua in 1858, dated from the Samnite wars in 300 B.C. It was made of copper and wood, and was unfor-

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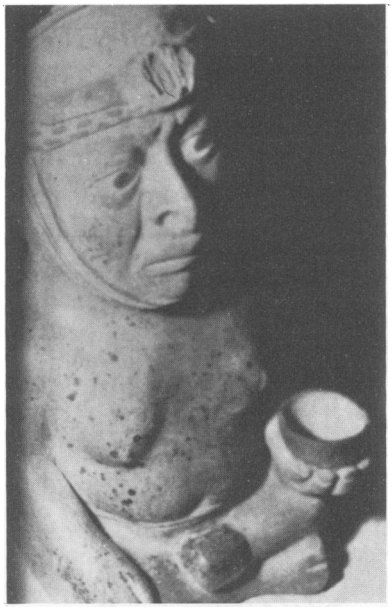

Figure 3. Peruvian figurine depicting amputee with cup-like prosthesis. (Reprinted from Bulletin of Prosthetics Research, Spring, 1972).

tunately lost during World War II when an air attack destroyed the museum of the Royal College of Surgeons.[18] In the middle ages, prostheses of iron were made by armorers for knights who had lost limbs in battle. Many knights refused to battle with these limbs, but the limbs were so heavy that they probably were of little use to someone not on horseback. An example of a sixteenth century lower limb prosthesis (Figure 4), was almost certainly not intended for walking because of the equinus of the foot, the short thigh

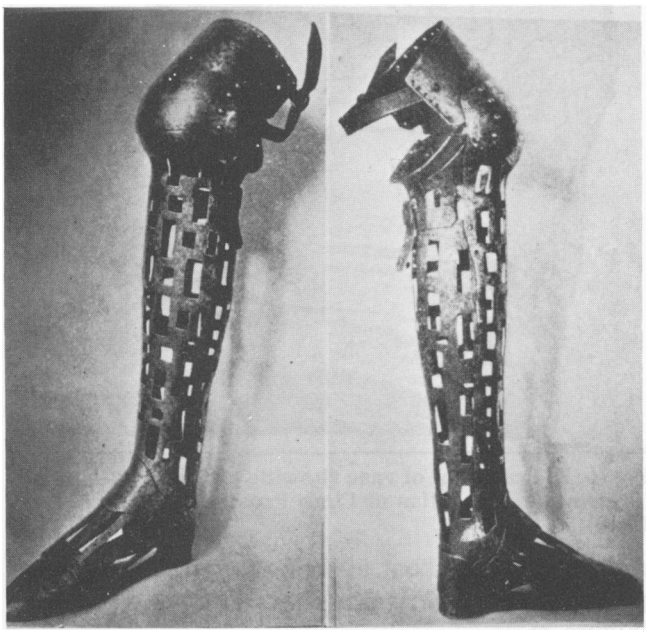

Figure 4. Sixteenth century lower limb prosthesis. (Reprinted from Historic Artificial Limbs, Paul B. Hoeber, Inc., 1930).

piece, and the two horizontal straps which would not have provided sufficient suspension. The knee does not extend fully, thus it was almost surely restricted to use while sitting in the saddle. Due to the fenestrations in the leg, this limb weighed only a little over three pounds.[13] Another prosthesis, made in the seventeenth century, was probably made for a congenital deformity rather than an amputation (Figure 5). This is an Italian leg with a wooden foot and iron leg-pieces,

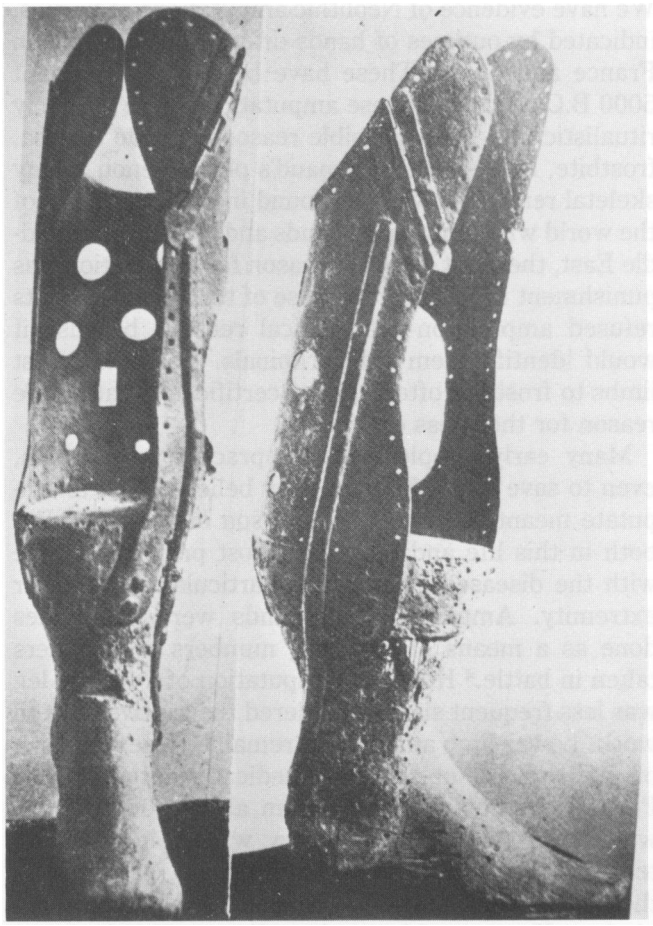

Figure 5. Seventeenth century lower limb prosthesis, probably made for a congenital deformity. (Reprinted from Historic Artificial Limbs, Paul B. Hoeber, Inc., 1930).

again perforated to save weight, and reinforced with two metal side-bars. The prosthesis, widest at its midpoint, contained a large oval opening at one side. Vittorio Putti, from whose 1930 book this photograph came, surmised that the prosthesis was most likely built for a man with a limb length inequality and a supinated, adducted foot, which could project through the medial hole.[13] The nature of the amputation process itself constituted one of the major impediments to the development of a good walking prosthesis. The pro-

cedure was usually done without anesthesia or control of bleeding. In Europe, anesthetic techniques included alcohol or opium, and the natives of South America chewed cocoa leaves and alkali, releasing cocaine.[4] Even so, the procedure had to be done quickly, and almost always by guillotine fashion, as described by surgeons from Hippocrates onward. Hippocrates described the use of ligatures, but this practice disappeared, and surgeons throughout the Dark Ages stopped bleeding by boiling oil or by crushing the stump. Obviously none of these techniques left the ideal stump for a prosthesis. The "styptics" used to control bleeding included vitriol, alum, and turpentine. Most surgeons now feel that these agents only stop bleeding from small vessels which would seal spontaneously, but the use of styptics remained common until 200 years ago. In the 1670's, vitriol was allegedly used to stop bleeding in all amputations at the Hotel-Dieu, the oldest and largest hospital in Paris, although some surgeons preferred the ligature of Paré.[17] One surgeon of the day, Rabel, so strongly believed in a special styptic, "vulnerary water," that he claimed it could prevent any wounded soldier from bleeding to death. He finally persuaded Louis XIV's minister of war to allow him to do a public demonstration. Before an assembled throng of physicians and surgeons at the Hôtel des Invalides, he amputated through the thigh of a soldier (presumably one who needed an amputation, although this is not specifically stated). Despite Rabel's frantic, repeated applications of his styptic and fresh bandages, the soldier bled to death in full view of the crowd. In the late eighteenth century, John Hunter of England still called oil of turpentine "the best, if not the only true styptic." Richard Wiseman, another British military surgeon of the seventeenth century also used oil of turpentine, but stated that the army surgeon "in the heat of the fight" would find cautery more effective.[17]

The use of cautery, a term used to describe any red-hot metal instrument, dates from the beginnings of surgery and continued well into the twentieth century. An ancient medical saying proclaimed: "Those diseases which medicine does not cure, iron cures; those which iron does not cure, fire cures; those which fire cannot cure are to be reckoned incurable."[17] Figure 6 shows several shapes of cauteries from the sixteenth century, along with a burner for heating them. Cautery was used as a hemostatic and anti-putrefactive agent, or a sort of early form of debridement. Paul of Aegina in the seventh century, the Arab physicians Albucasis in the tenth century and Avicenna in the eleventh century advocated cautery. In his book, "On Surgery and Instruments," Albucasis praised the use of the "actual" cautery, meaning a red hot iron, as opposed to "potential" cauteries, such as caustics. Caustics could spread beyond the desired area, whereas, "fire, on account of the nobility of its nature, has no such effect unless it is overdone."[17] Albucasis used cautery for debridement of infection as well as for hemostasis in fresh wounds. He preferred an iron cautery, although gold, bronze, and other metals were also in use. In 1600, a German surgeon, Fabricius Hildanus, recommended a heavy, red

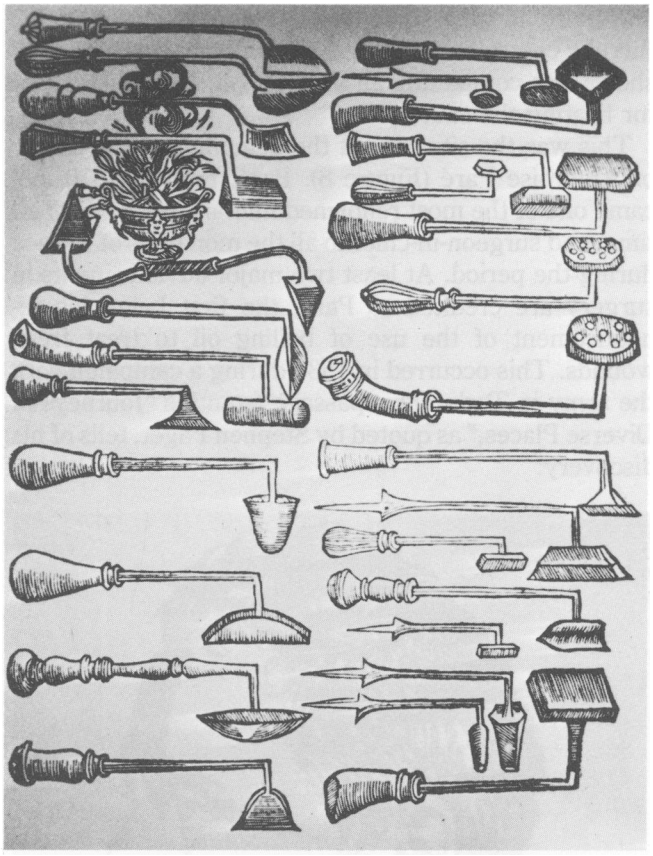

Figure 6. Cauteries and burner for heating. (Reprinted from Ambroise Paré and His Times, The Knickerbocker Press, 1897).

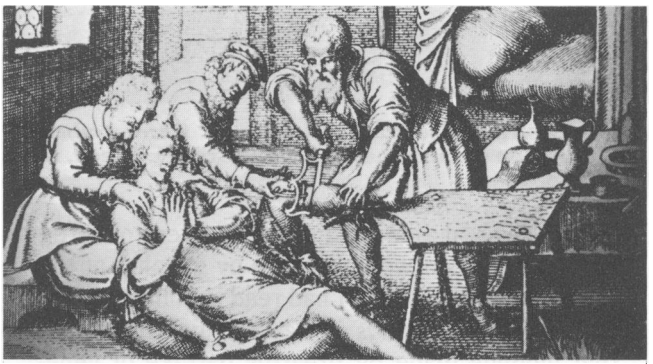

Figure 7. The German surgeon, Fabricius Hildanus, completing an amputation. (Reprinted from The Rise of Surgery: From Empiric Craft to Scientific Discipline, University of Minnesota Press, 1978).

hot knife to sever the soft tissues in amputations, thereby controlling all bleeding immediately.[17] Figure 7 shows him completing an amputation. Note the firepot for heating the cautery.

This was the situation at the beginning of the career of Ambroise Paré (Figure 8). Paré, born in 1510, became one of the most renowned military surgeons of all time, and surgeon-in-chief to all the monarchs of France during the period. At least two major advancements in surgery are credited to Paré, the first being his renouncement of the use of boiling oil to treat fresh wounds. This occurred in 1537 during a campaign with the army in Turin. This passage from his "Journeys in Diverse Places," as quoted by Stephen Paget, tells of his discovery:

Figure 8. Ambroise Paré. (Reprinted from Ambroise Paré, Surgeon of the Renaissance, Warren H. Green, Inc., 1967).

> "Now I was at this time a fresh-water soldier; I had not yet seen wounds made by gunshot at the first dressing. It is true I had read in John de Vigo, first book, *Of Wounds in General,* eighth chapter, that wounds made by firearms partake of venenosity, by reason of the powder; and for their cure he bids you cauterize them with oil of elders scalding hot, mixed with a little treacle. And to make no mistake, before I would use the said oil, knowing this was to bring great pain to the patient, I asked first before I applied it, what the other surgeons did for the first dressing; which was to put the said oil, boiling well, into the wounds, with tents and setons; wherefore I took courage to do as they did.* At last my oil ran short, and I was forced instead thereof to apply a digestive made of the yolks of eggs, oil of roses, and turpentine. In the night I would not sleep in quiet, fearing some default in not cauterising, that I should find the wounded to whom I had not used the said oil dead from the poison of their wounds; which made me rise very early to visit them, where beyond my expectation I found that those to whom I had applied my digestive medicament had but little pain, and their wounds without inflammation or swelling, having rested fairly well that night; the others to whom the boiling oil was used, I found feverish, with great pain and swelling about the edges of their wounds. Then I resolved never more to burn thus cruelly poor men with gunshot wounds.
>
> While I was in Turin, I found a surgeon famed above all others for this treatment of gunshot wounds; into whose favour I found means to insinuate myself, to have the recipe of his balm, as he called it, wherewith he dressed gunshot wounds. And he made me pay my court to him for two years, before I could possibly draw the recipe from him. In the end, thanks to my gifts and presents, he gave it to me; which was to boil in oil of lilies, young whelps just born, and earth-worms prepared with Venetian turpentine. Then I was joyful, and my heart made glad, that I had understood his remedy, which was like that which I had obtained by chance.
>
> See how I learned to treat gunshot wounds; not by books."[11]

He never again used boiling oil, but his balm included turpentine, and he continued to use both "actual" and "potential" cautery, for several more years. About fifteen years later, however, he made his second and most famous contribution, the use of the ligature for hemostasis in amputations. Ligatures were known before Paré. They had been described by Hippocrates, Celsus, Avicenna, Guy de Chauliac, de Vigo, Vesalius, Tagault, and Croce, and in Paré's time the use of the ligature in fresh wounds was not uncommon.[17] Friedmann feels that the ligature was probably used by early Civilizations in South America.[4] Certainly in Paré's hands the use of the ligature on major vessels in amputation surgery was, if not pioneered, at least championed and

made widespread, Quoting from Paré's "Opera Omnia," as given in Paget:

> "Here I confess freely and with deep regret that formerly I practised not this method but another. Remember, I had seen it done by those to whom these operations were entrusted. So soon as the limb was removed, they would use many cauteries, both actual and potential, to stop the flow of blood, a thing very horrible and cruel in the mere telling . . . And truly of six thus cruelly treated scarce two ever escaped, and even these were long ill, and the wounds thus burned were slow to heal, because the burning caused such vehement pains that they fell into fever, convulsions, and other mortal accidents; in most of them moreover, when the scar fell off, there came fresh bleeding which must again be staunched with the cauteries, which thus repeated, consumed a great quantity of flesh and other nervous parts. By which loss the bones remained long afterward bare and exposed so that, for many, healing was impossible and they had an ulcer there to the end of their lives, which prevented them from having an artificial limb. Therefore I counsel the young surgeon to leave such cruelty and inhumanity and follow my method of practice, which it pleased God to teach me, without I had ever seen it done in any case, no nor read of it."

He retained the cautery in his first few amputations in case the ligatures should fail, but they did not, and he eventually gave up cautery entirely. He ligated major vessels in continuity before severing them. He would pull smaller vessels away from the wound with his Crowe's beake, the forerunner of our hemostat, and

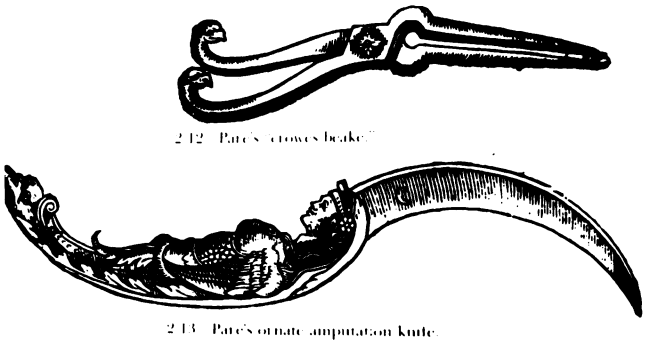

Figure 9. Surgical instruments used by Paré. (Reprinted from The Rise of Surgery: From Empiric Craft to Scientific Discipline, University of Minnesota Press, 1978).

then ligate them (Figure 9). Some have called Paré's contribution "the greatest improvement that has ever been made in operative surgery." Stephen Paget, one of his biographers, said in his 1896 edition, "Prometheus, who brought fire to suffering mortals, is not to be compared with this good surgeon, who took it away from them."[10] Paré's own comments on the case, however, were more modest: "I returned to Paris, with my gentleman whose leg I had cut off: I dressed him, and God cured him. I sent him home happy with a wooden leg, and he was well satisfied, saying that he had got off cheap." This was sometime between 1552, when he published a book advocating cautery, and 1564, when his next book retracted this and advised the reader never to use cautery for amputations. Paré's rediscovery of ligatures came in about 1560. The next comment on ligatures came in 1597, when Peter Lowe of Scotland said, "Where there is putrefaction, stay the flux of blood by Cauters actuals, and where there is no putrefaction, use the ligator."[17] The Paris surgeon Pierre Dionis, in 1673, preferred ligatures but noted that he resorted to buttons of vitriol when ligatures failed. By 1707, Dionis declared that surgeons no longer used actual cauteries, and said that he displayed such instruments to his students "rather to excite horror with regard to their cruelty than to advise their use."[17] However, fifty years later, a Montpelier surgeon claimed that surgical operations were not usually undertaken until the cautery was prepared, and in a 1754 essay for the French Royal Academy of Surgery, Guillaume Louis concluded that "Fire will always be a means of stopping hemorrhage in very urgent situations.[17] Albrecht Middledorpf in 1854 introduced a galvanocautery, and C. Pacquelin in 1876 invented an electrocautery. In 1928, Harvey Cushing and W. T. Bovie produced the surgical diathermy unit, with cutting and coagulating currents, which we call the Bovie today.[17]

Some have puzzled over the slow acceptance of what seems to us an obvious surgical breakthrough. However, we must remember how much slower the use of the ligature was, at a time when anesthesia and skilled help were almost non-existent. A German study in 1890 found that in above-knee amputations without cautery an average of 53 ligatures was needed.[17] Many of these were on small vessels which previously would have been cauterized. Even in above-knee amputations for arteriosclerosis, the average was 25 ligatures. Furthermore, the surgeon of those years usually operated alone, with only servants to restrain the patient. Woodall used five assistants for amputating through live tissue; Dionis used six. The French military surgeon Hughes Ravaton (1768) had four aides: two to hold the patient, one to offer the patient cordials, and the fourth to pass instruments and help with the dressing.[17] Skilled help to tie ligatures or hold the Crowes

beake was not easy to find. Even Jacques Guillemeau, Paré's favorite pupil, gave up the use of the ligature after Paré's death. In his book, Guillemeau states: "The leg now being extirpated . . . we must as then stoppe, and restrain the bleeding, which we must do through the imposition of the fingers on the mouths, or apertios, of the veins, which we must either bind or else cauterize, the one or the other according as the same shall be needful and requisite . . . Supposing to hold on the veins with the Crowesbill, and so to bind them, do most commonly chance to break between the Crowesbill . . . we are in the end constrained to use the actual cautery." Guillemeau also stated that if the limb to be amputated was gangrenous, hemorrhage was "far more stopped through the applications of glowing cauteries than by ligation."[17] Paré did not abandon the use of cautery for debridement of dead tissue in gangrenous wounds, including the use of caustics. He seared the end of a bone following a forearm amputation "to dry up the perpetual flow of corrupt matter," and he added that the patient "was wondrously delighted by the application of such actual cauteries, a certain tickling running the whole length of the arm by reason of a gentle diffusion of the heat by applying the caustic."[17]

Hippocrates and Celsus advocated this, and when Leonides in the first century A.D. amputated a breast for cancer, he used the cautery for hemostasis and to dessicate all visible traces of the tumor. In the fourteenth century the French surgeons Guy de Chauliac and Henri de Mondeville used cautery to combat would sepsis, and this practice lasted well into the twentieth century. One of the scourges of the pre-antibiotic era was hospital-acquired gangrene. John Bell said in 1830 "When hospital gangrene rages in a great hospital it is like the plague. No operation dare be performed, every cure stands still, every wound becomes a sore, and every sore is apt to run into gangrene."[17]

Woodall, in the early 1600's, often used cautery to sear dead tissue in amputations, occasionally at the first dressing change postoperatively, and frequently at the second dressing change. He said that it was safe for patients, but because of the public's hatred of cautery, he added "I advise it to be privately absconded for the reputation's sake."[17]

In 1783, Ponteau of Lyons said that the best therapy for hospital gangrene was the destruction of the part "by fire," and he used the actual cautery, but he added that boiling oil or a caustic could be used, if, as he put it, "the cowardliness of the patient, or perhaps of the surgeon, prevent it."[17] In 1813, when up to 500 wounded per day poured into Montpellier from Napoleon's Peninsular War, hospital gangrene became rampant. Delpech, of the surgical clinic at the University, suggested that as an experiment the students should try cautery on all wounds in 150 men with infected bullet wounds from the siege at Pampeluna. To everyone's surprise, almost all the patients recovered, and Delpech eventually concluded in his monograph that no treatment had the "speed and constancy" of the cautery. Berkely Moynihan, of the Leeds school of surgeons, writing on wounds of the knee joint in World War I, said that "a preliminary sterlization of the tract with the actual cautery is an undoubted advantage." Even as late as 1935, August Bier used electrical cautery in Berlin hospitals to control infections of the hand in 230 patients.[17]

The use of cautery was very slow to die, even though ligatures had been proven effective, because cautery gave so much faster control of bleeding. The tourniquet represented a great boon to the use of the ligature. This certainly existed at the time of Paré. Guy de Chauliac used a tight band above and below the site of amputation to reduce pain and minimize bleeding by compressing the soft tissues against the bone. In the sixteenth century Leonardo Botallo used three bands and operated between the lower two. Fabricius tightened a band above the site of surgery by twisting it with a stick, and Johannes Scultetus of Ulm invented a screw compressor in the 1600's. In 1718, J. L. Petit devised the most

Figure 10. Tourniquet designed by J.L. Petit (Reprinted from The Rise of Surgery, University of Minnesota Press, 1978).

effective tourniquet (Figure 10). This instrument, tied to the abdomen, could not slip, and it put direct pressure on the major artery of the limb to be amputated, giving good hemostasis.[17] This certainly made the use of ligatures much simpler.

Another important consideration to be resolved was the level of amputation. Hippocrates in his writings taught amputation through devitalized tissue rather than living to avoid the risk of hemorrhage. Celsus taught to operate above the dead tissue, and Paré revived this: "As to that which is necessary (say you), to use fire after amputations of the members, in order to consume and check the putrefaction of which is common to gangrene and to mortifications, that in truth hath no place here because the practice is to amputate always the part above that portion which is mortified and corrupted, as wrote and recommended Celsus, to perform the amputation on that which is healthy, rather than to leave any of the putrefied."[9] Paré's teachings again were slow to be adopted. In 1639 the British surgeon John Woodall recommended operating through the upper level of dead tissue; he reasoned that this was painless for the patient, and after the amputation the surgeon could gradually whittle away at the dead tissue until it was gone.[17]

Another major controversy, still existent is the open versus closed treatment of amputations. Hippocrates, since he amputated through the dead tissue, left his amputation stumps open, to heal by granulation. This left a projecting segment of bone which later had to be removed by saw or rongeurs, which many of us have experienced. Hugh of Lucca, in the thirteenth century, (who founded the Bologna school), his pupil Theodoric, and Henri de Mondeville felt that all wounds, even contaminated ones, had to be closed. It was more common to close wounds than to leave them open, at least until the 1800's. French surgeons frequently closed wounds over small pieces of linen called charpies, until the advent of the antiseptic era. Dominique Larrey, Napoleon's military surgeon-in-chief of the late 1700's and early 1800's, learned in his early campaigns that primary closure of gunshot wounds produced a high complication rate, and in later years he advocated open treatment of all such wounds. Edward Alanson of Liverpool reported in 1782 a series of 35 major amputations without a death, an unusual success rate for that era. He approximated wound edges with adhesive tape, but did not close them.[17] In the early 1800's, several surgeons, including Vincenz Kern in 1826 and Liston in 1841, advocated leaving a wound open for a few hours after surgery to allow it to develop a "glaze." Liston reported a mortality rate of 11.4 per cent for major amputations. This is quite good considering that in more complicated cases, to save time (so that he could use both hands) he would hold the knife by its handle in his mouth.[17]

The official Union Army Manual of 1861 stated that "when the wound is extensive, as in cases of amputation, it is far preferable to leave the wound open, with a piece of wet lint, or a thin compress, interposed between the lips, for two or three hours, until the surface has become glazed." Eventually they recommended allowing the wounds to heal by granulation.[17] Considering the slow acceptance of all these developments, (the use of the tourniquet, amputating through healthy tissue, the use of ligatures, and the use of delayed closure), the reader's attention is directed to a passage from Paré which is truly remarkable for its summary, in the mid 1500's, of much of what we use today:

> "You shall certainly know that a Gangreene is turned into a Sphacell, or mortification, and that the part is wholly and thoroughly dead, if it looke of a blacke colour, and bee colder than stone to your touch, the cause of which coldnesse is not occasioned by the frigiditie of the aire; if there bee a great softnesse of the part, so that if you presse it with your finger it rises not againe, but retaines the print of the impression. If the skinne come from the flesh lying under it; if so great and strong a smell exhale (especially in an ulcerated Sphacell) that the standers by cannot endure or suffer it; if a sanious moisture, viscide, greene or blackish flow from thense; if it bee quite destitute of sense and motion, whether it be pulled, beaten, crushed, pricked, burnt, or cut off. Here I must admonish the Young Chirurgion, that hee be not deceived concerning the losse or privation of the sense of the part.
>
> For I know very many deceived as thus; the patients pricked on that part would say they felt much paine there. But that feeling is oft deceiptfull, as that which proceeds rather from the strong apprehension of great paine which formerly reigned in the part, than from any facultie of feeling as yet remaining. A most cleare and manifest argument of this false and deceitful sense appeares after the amputation of the member; for a long while after they will complaine of the part which is cut away.
>
> Verily it is a thing wondrous, strange and prodigious, and which will scarse be credited, unlesse by such as have seene with their eyes, and heard with their eares the patients who have many moneths after the cutting away of the Legge, grievously complained that they yet felt exceeding

great paine of that Legge, so cut off. Wherefore have a special care least this hinder your intended amputation; a thing pittifull, yet absolutely necessary for to preserve the life of the patient and all the rest of his body, by cutting away of that member which hath all the signes of a Sphacell and perfect mortification; for otherwise the neglected fire will in a moment spread over all the body, and take away all hope of remedy; for thus Hippocrates wisheth; That Sections, Ustions, and Terebrations must be performed as soone as neede requires.

Where Amputation must be made.

It is not sufficient to know that Amputation is necessary; but also you must learne in what place of the dead part, it must bee done, and herein the wisedome and judgement of the Chirurgion is most apparent. Art bids to take hold of the quicke, and to cut off the member in the sound flesh; but the same art wisheth us, to preserve whole that which is sound, as much as in us lies. I will shew thee by a familiar example how thou maist carry thy selfe in these difficulties. Let us suppose that the foote is mortified even to the anckle; here you must attentively marke in what place you must cut it off. For unlesse you take hold of the quicke flesh in the amputation, or if you leave any putrefaction, you profit nothing by amputation, for it will creepe and spread over the rest of the body. It befits Physicke ordained for the preservation of mankind, to defend from the iron or instrument and all manner of injuries, that which enjoyes life and health. Wherefore you shall cut off as little of that which is sound as you possibly can; yet so that you rather cut away that which is quicke, than leave behind any thing that is perished, according to the advice of Celsus. Yet oft times the commodity of the action of the rest of the part, and as it were a certaine ornament thereof, changes this counsell. For it you take these two things into your consideration they will induce you in this propounded case and example, to cut off the Legge some five fingers breadth under the knee. For so the patient may more fitly use the rest of his Legge and with lesse trouble, that is, he may the better go on a woodden Legge; for otherwise, if according to the common rules of Art, you cut it off close to that which is perished the patient will be forced with trouble to use three Legges instead of two.

For I so knew Captaine Francis Clerke, when as his foote was strucken off with an iron bullet shot forth of a man of warre, and afterwards recovered and healed up, hee was much troubled and wearied with the heavy and unprofitable burden of the rest of his Legge, wherefore though whole and sound he caused the rest thereof to bee cut off, some five fingers breadth below his knee; and verily hee useth it with much more ease and facility than before in performance of any motion. Wee must doe otherwise if any such thing happen in the Arme; that is, you must cut off as little of the sound part as you can. For the actions of the Legges much differ from these of the armes, and chiefly in this that the body rests not, neither is carried upon the armes, as it is upon the feete and Legges.

How the section or amputation must be performed.

The first care must be of the patient's strength, wherefore let him be nourished with meats of good nutriment, easie digestion, and such as generate many spirits; as with the yolkes of Egges, and bread tosted and dipped in Sacke or Muskedine. Then let him bee placed, as is fit, and drawing the muscles upwards toward the sound parts, let them be tyed with a straite ligature a little above that place of the member which is to be cut off, with a strong and broad fillet like that which women usually bind up their haire withall; This ligature hath a threefold use; the first is, that it hold the muscles drawne up together with the skin, so that retiring backe presently after the performance of the worke, they may cover the ends of the cut bones, and serve them in stead of boulsters or pillowes when they are healed up, and so suffer with lesse paine the compression in susteining the rest of the body; besides also by this meanes the wounds are the sooner healed and cicatrized; for by how much more flesh or skinne is left upon the ends of the bones, by so much they are sooner healed and cicatrized. The second is, for that it prohibites the fluxe of blood by pressing and shutting up the veines and arteries. The third is, for that it much dulls the sense of the part by stupefying it; the animall spirits by the straite compression being hindred from passing in by the Nerves: Wherefrom when you have made your ligature, cut the flesh even to the bone with a sharpe and well cutting incision knife or with a crooked knife, such as is here expressed.

Now you must note, that there usually lyes betweene the bones, a portion of certaine muscles, which you cannot easily cut with a large incision

or dismembering knife; wherefore you must carefully divide it and separate it wholly from the bone, with an instrument made neately like a crooked incision knife. I thought good to advertise thee hereof; for if thou shouldest leave any thing besides the bone to bee divided by the saw, you would put the patient to excessive paine in the performance thereof; for soft things as flesh tendons and membranes, cannot be easily cut with a saw. Therefore when you shall come to the bared bone, all the other parts being wholly cut asunder and divided, you shall nimbly divide it with a little saw about some foote and three inches long, and that as neare to the sound flesh as you can. And then you must smooth the front of the bone which the saw hath made rough.

How to stanch the bleeding when the member is taken off.

When you have cut off and taken away the member, let it bleed a little according to the strength of the patient, that so the rest of the part may afterwards be lesse obnoxious to inflammation and other symptomes; Then let the Veines and Arteries be bound up as speedily and streightly as you can; that so the course of the flowing blood may bee stopped and wholly stayed. Which may be done by taking hold of the vessells with your Crowes beake, whereof this is the figure. The ends of the vessells lying hid in the flesh, must be taken hold of and drawn with this instrument forth of the muscles whereinto they presently after the amputation withdrew themselves, as all parts are still used to withdraw themselves towards their originalls. In performance of this worke, you neede take no great care, if you together with the vessells comprehend some portion of the neighbouring parts, as of the flesh, for herof will ensue no harme; but the vessells will so bee consolidated with the more ease, than if they being bloodlesse parts should grow together by themselves. To conclude, when you have so drawne them forth, binde them with a strong double thred.

How after the blood is stanched, you must dresse the wounded member.

When you have tyed the Vessells, loose your Ligature which you made above the place of amputation; then draw together the lippes of the wound with foure stitches made acrosse, having taken good hold of the flesh; for thus you shall draw over the bones that part of the skinne and cut muscles drawne upwards before the amputation, and cover them as close as you can, that so the ayre may the lesse come at them, and that so the wound may bee the more speedily agglutinated. But when wee say, draw together the lippes of the wound with foure stitches, you must not so understand it, as that you must endeavour, to draw them so close as to touch each other, for that is impossible; for the stitches would sooner breake out, and so the part would lye bare. Wherefore it will be sufficient to draw them indifferent close together, that so you may suffer the skinne and flesh thereunder to enjoy its former liberty which it possest before the drawing up, and so in fine by natures assistance, the wound may be the more easily agglutinated.

How you must stoppe the bleeding, if any of the bound vessels chance to get loose.

The business hitherto being performed as we said, if peradventure it happen that any bandage of any of the vessels be unloosed; then must you againe binde the member with that kinde of Ligature which you did before the amputation thereof. Or else, which is better, more easily and lesse painefull, let your servant taking hold of the member with both his hands, pressing his fingers strait, stoppe the passage of the loosed vessell, for so hee may stanch the bleeding. Then let the worke-master take a needle some foure fingers long, square, and having sharpe edges, drawing after it a three or foure doubled strong thred. With this let him binde the vessell after the following manner. Let him thrust his needle on the outside into the flesh, some halfe fingers breadth from the loosed vessell until he come to the end thereof, then let him put it about it, and bring it backe againe, but so that there be no more than the space of a fingers bredth betweene the going in, and comming forth of the needle. In this space let him put a linnen ragge three or foure times doubled, and thereupon bind somewhat straite the two ends of the thred together. For so he shall hinder the knot from hurting the flesh which lyes under it in the bindings, and also adde strength thereto. For so the bound up orifice of the vessell will in short space be agglutinated to the adjoyning flesh, and that so firmely, that there hath never beene seene, any one drop of blood to have flowed from a vessell so bound up. But if the blood which flowes forth proceede from any small vessell, you must not use this suture and ligature, nor

make any such great matter thereof; for it will quickly be stanched by the only application of Astringents presently to be mentioned."

In that one passage Paré described the following which seem so well known to us, but certainly were not in widespread use four hundred years ago: the principle of amputation through living tissue, the use of the tourniquet, the use of ligatures on major vessels, the hemostat, allowing small vessels to seal themselves, the standardized below-knee stump regardless of the level of gangrene, the preservation of length in forearm amputations, the phantom limb syndrome, retracting soft tissue before cutting the bone in order to get better stump coverage, delayed closured, and the use of a modified suture-ligature with bolsters for difficult bleeding. For any essay written in 1560, it is remarkable. Paré could probably enter a modern operating room and do an amputation which would be creditable by anyone's standards.

How, one may ask, did all of this lead to progress for the amputee? Among other things, surgeons armed with the new techniques of ligature and tourniquet began to grow more bold. Whereas formerly only lower leg amputation had been done successfully (due to the fact that it was almost impossible to stop blood flow in the major vessels of the thigh by cautery), William Clowes in 1588 performed a successful above-knee amputation for gangrene, and another was reported by Fabricius in 1614. In 1781 John Warr successfully amputated through the shoulder, and by 1803, Larrey, the French military surgeon, successfully amputated several times at the shoulder, and also through the hip. In this country, Walter Brashear of Kentucky successfully amputated through the hip in 1806.[2] Nathan Smith, also in the United States, published the first report of a planned operation through the knee joint in 1825.[2] Billroth allegedly attempted a hindquarter amputation but Gordon-Taylor published the first successful series in 1940. Until the development of anesthesia, in all of these procedures, speed was of the essence. Jacques Lisfranc of Paris in the early 1800's used 1000 cadavers per year to teach operative surgery, and could amputate the thigh of a cadaver in ten seconds. He felt that a critical part of the technique was to avoid kneeling on the floor at any time, since one wasted too much time regaining the standing position.[17] Benjamin Bell of Edinburgh divided all except the bone in a thigh amputation in six seconds; James Woods of New York did a thigh amputation in nine seconds. Dominique Larrey averaged three minutes, and could disarticulate a shoulder in seventeen seconds, not counting ligatures and dressings.[17] Ferguson took from twelve to twenty seconds to amputate through the hip joint. These techniques, of course, were not without their complications. A colleague of Liston in London amputated a thigh in a few seconds, but in his zeal he included two fingers of his assistant, and both testes of his patient.[17] Larrey, in the Moscow campaign, did 200 amputations in the first 24 hours, or one every seven minutes, day and night.[17]

Most amputations done in this rapid fashion were relatively crude, guillotine operations, with bone and soft tissue cut at the same level. The "chop" amputation leaves an unsatisfactory result because of protruding bone. While most were concerned with speed, some were working on improved techniques to leave a better stump. Paré recommended retracting skin and muscle proximally before severing the bone, to leave more coverage for the bone. True flap amputations were first credited to James Younge of Plymouth in 1679.[17] Verdun of Amsterdam, in 1696, and Revation and Vernal of France in the 1700's also designed simple flaps. In 1837 Robert Liston introduced a flap amputation like the one used today.[2] Gradually, as the flap amputation replaced the circular, knives changed from the curved of

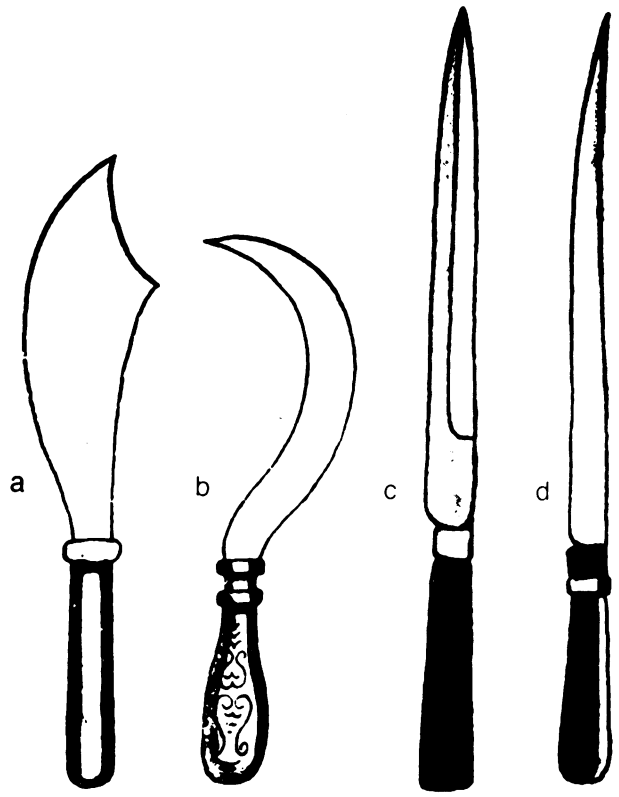

Figure 11. Amputation knives of the early 1800's (Reprinted from The Rise of Surgery, University of Minnesota Press, 1978).

Fabricius to the straight of Liston (Figure 11).[17] Malgaigne in Paris introduced a racquet type incision. In 1807, Charles Bell illustrated a well performed thigh

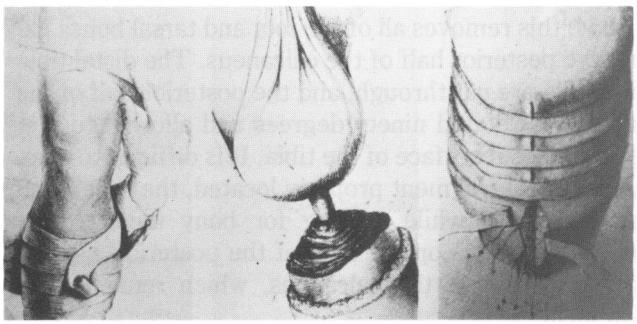

Figure 12. Use of muscle retraction in thigh amputation. (Reprinted from The Rise of Surgery, University of Minnesota Press, 1978).

amputation using the same principle of muscle retraction (Figure 12).[17] Both flap and circular amputations have been used.

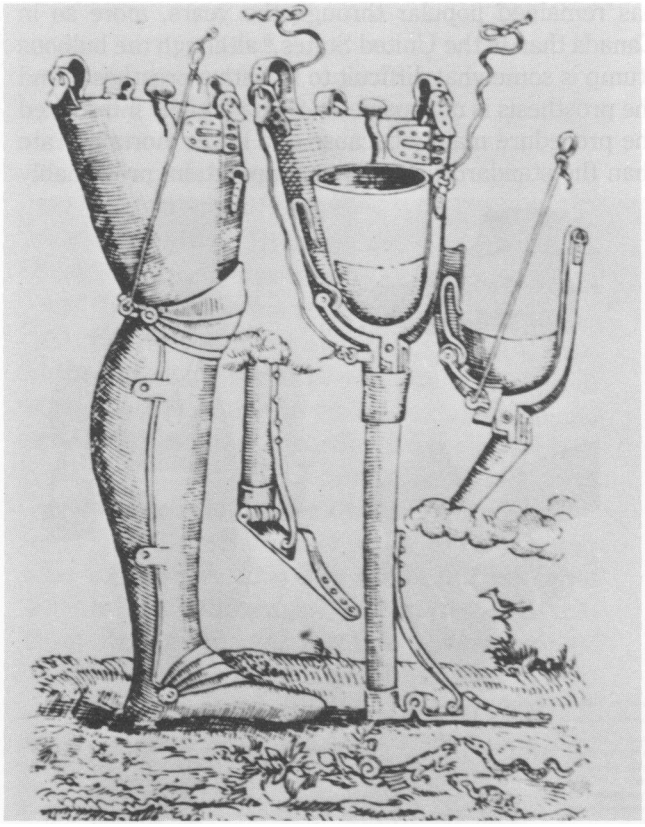

Figure 13. Paré's above knee prosthesis with articulated joints (Reprinted from Limb Prosthetics—1972, Robert E. Krieger Publishing Co., 1972).

As the amputation stump improved, surgeons began to design true walking prostheses. Paré designed the first known above-knee prosthesis with articulated joints (Figure 13). Verdun, one of the designers of the flap type amputation also produced the first limb which allowed knee motion for below-knee amputees. The foot was wooden, and the socket made of copper lined by leather (Figure 14). This resembled the thigh corset,

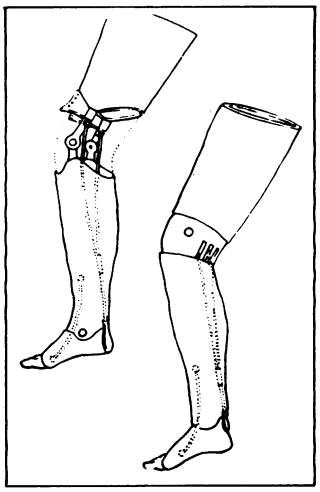

Figure 14. Verdun's innovation of a below knee prosthesis allowing knee motion (Reprinted from Limb Prosthetics—1972, Robert E. Krieger Publishing Co., 1972).

below-knee prostheses still in use today, but for some reason the design was lost until re-introduced by Serré in 1826.[18] The next advance in the above-knee prosthesis after Paré was by James Potts of London in 1800. His prosthesis was lighter because it had a wooden socket and shank, unlike Paré's metal one. It had a steel

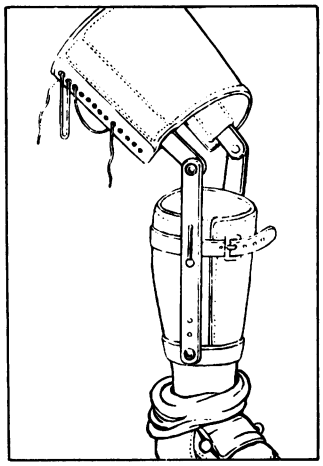

Figure 15. Prosthesis designed by James Potts of London in 1800 (Reprinted from Limb Prosthetics—1972, Robert E. Krieger Publishing Co., 1972).

knee joint, an articulated foot, and cords connecting the knee and ankle so that toe lift was coordinated with knee flexion. The Marquis of Anglesea used this after he lost a leg in the battle of Waterloo, and it became known as the Anglesea leg (Figure 15).[18] This was introduced into the United States in 1839 and modifications were made, including a rubber plate in the ankle to reduce jarring and a rubber sole for grip. It eventually became known as "the American leg." In 1842, Martin placed the knee hinges more posteriorly to give a more stable knee. The foot had a spring-controlled joint within in. Bly in 1858 introduced an ivory and rubber ball and socket ankle joint with variable tension, and in 1860 Marks substituted a hard rubber foot for the wooden variety.[1] After the Civil War J.E. Hanger, one of the first on the Southern side to lose a limb, replaced

the cords of the Anglesea leg with rubber bumpers at the ankle which could vary plantarflexion and dorsiflexion, a design which remained almost universal until recently. A large prosthetics firm still bears his name.[18] He also popularized the suction socket. A quotation from his patent states "The first part of this invention relates to the bucket or socket of artificial legs or arms intended to receive the stump, and it consists in the fastening of such bucket to the stump by means of atmospheric pressure in such a manner that the straps usually employed for this purpose can be dispensed with and at the same time a perfect fit of the bucket is obtained." His leg had adjustable springs for the toes so that the foot could adapt itself to the ground. For some reason it was only decades later that this prosthesis became the universally accepted limb which it is today.[1] The production of prostheses received a tremendous boost during the Civil War, with 30,000 amputations performed by the Union Army Medical Corps alone. Marks introduced the leather or parchment covering for the wooden socket, and Herrmann of Prague introduced aluminum moving parts to replace the steel. Limbs were produced during that period for $75 to $150 each.[1]

Also, new techniques of amputation were introduced, most of them representing attempts to produce end-bearing stumps. Most amputations were devised after the introduction of ether for anesthesia at Massachusetts General Hospital in 1846. Before then, few surgeons wanted anything but the quickest possible amputation. One of the first new amputations was introduced by Frances Chopart in 1792. He proposed a disarticulation through the talonavicular and calcaneocuboid joints. This was for a time, a popular amputation. There was a marked tendency for the hindfoot to go into equinus and varus, due to unbalanced muscle pull. Furthermore, the normal upward inclination of the plantar surface of the calcaneus was no longer supported by the rest of the arch. The plantar surface naturally came to rest flat on the ground, forcing the calcaneus into equinus. The weight bearing forces on the talus were thus directed somewhat forward as well as straight down, and it would almost invariably slide anteriorly and medially to the calcaneus, resulting in subtalar joint pain, and revision of the amputation.[14] Lisfranc described his metatarsal-tarsal disarticulation in 1815. This operation, although relatively quick, requires a long plantar flap to cover the bones of the tarsus, and since it is often the sole of the foot which is most destroyed, this amputation has found relatively little use. Also the Lisfranc amputation removes the tibialis anterior and the peronei, and tends to destroy the arch of the foot.[15] Nicolai Pirogoff introduced his amputation in 1854; this removes all of the foot and tarsal bones except the posterior half of the calcaneus. The distal tibia and fibula are cut through, and the posterior half of the os calcis is rotated ninety degrees and allowed to rest against the cut surface of the tibia. It is difficult to keep the calcaneal fragment properly located, the rehabilitation is slowed while waiting for bony union,[14] and weight bearing is on the skin of the posterior, not the plantar, aspect of the calcaneus, which remains less than ideal.

James Syme in 1843 introduced extirpation of the entire foot, leaving only the heel pad. The distal ends of the tibia and fibula are removed with a saw, and the heel pad is swung up to cover the cut surface of the tibia, again giving an end-bearing stump. This has the advantage of requiring no bony healing. The procedure has remained popular through the years, more so in Canada than in the United States,[6] although the bulbous stump is somewhat difficult to fit with a prosthesis, and the prosthesis is not cosmetic. Syme initially introduced the procedure mainly because of a lower mortality rate than the standard below-knee amputation, presumably

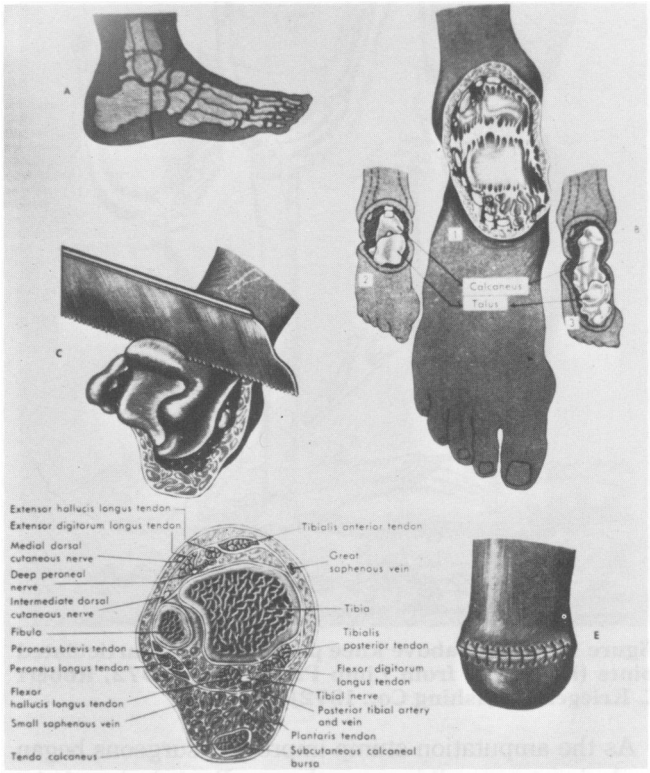

Figure 16. Method of Syme amputation (Reprinted from An Atlas of Amputations, C.V. Mosby, 1949).

due to less exposure of tissues and a lower infection rate. Today its main advantage is to provide a stump on which the amputee can walk for short distances without crutches or prosthesis. Figure 16 shows the technique of the Syme operation. Gritti in 1857 introduced an

operation designed to give an end-bearing above-knee amputation stump. He did a supracondylar osteotomy of the femur, removed the cartilage from the patella (leaving the quadriceps mechanism attached), and fixed the patella to the cut surface of the femur. This operation, modified slightly by Stokes in 1870, has since been known as the Gritti-Stokes procedure.[15] Like similar procedures in the foot, it has proven difficult to hold the cut patella in place, particularly since the quadriceps constantly tends to pull it up. The time required for bony healing delays rehabilitation and if healing is successful, late osseous changes often make the stump unuseable.[15]

What new developments have occurred in amputations and prostheses since 1900? Refinements in detail have occurred, but the basic principles have changed little. The circular amputation has not been abandoned, and in fact, the Surgeon General in World War II required that all amputations in forward areas be done in circular fashion, as distal as possible, and that the

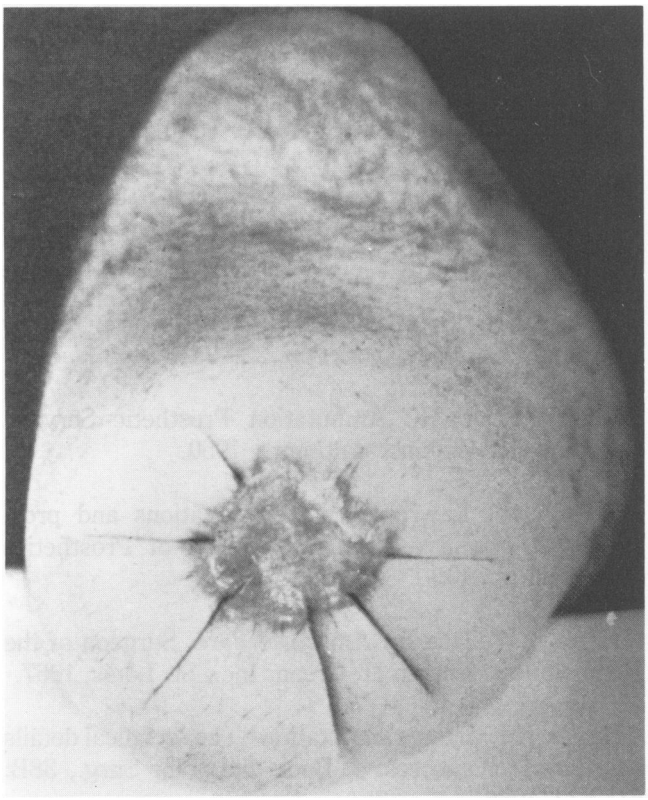

Figure 17. End result of circular amputation stump treated with postoperative skin traction (Reprinted from An Atlas of Amputations, C.V. Mosby, 1949).

wounds be left open with traction on the skin edges.[12] The ideal end result for the stump is seen in Figure 17. Occasionally this stump requires excision of the distal scar, but in cases where the scar is this small, thanks to

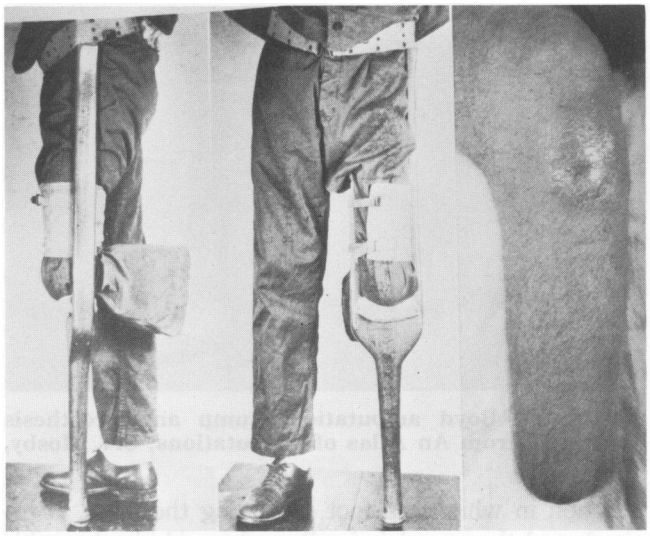

Figure 18. Peg leg type prosthesis on below knee amputee (Reprinted from An Atlas of Amputations, C.V. Mosby, 1949).

carefully applied traction, scar removal is a minimal procedure. World War II resulted in some interesting homemade prostheses, many made from scrap materials in prisoner-of-war camps. Figure 18 shows the classic Long John Silver peg leg, with the patient kneeling in the prosthesis. Until recently, some loggers used

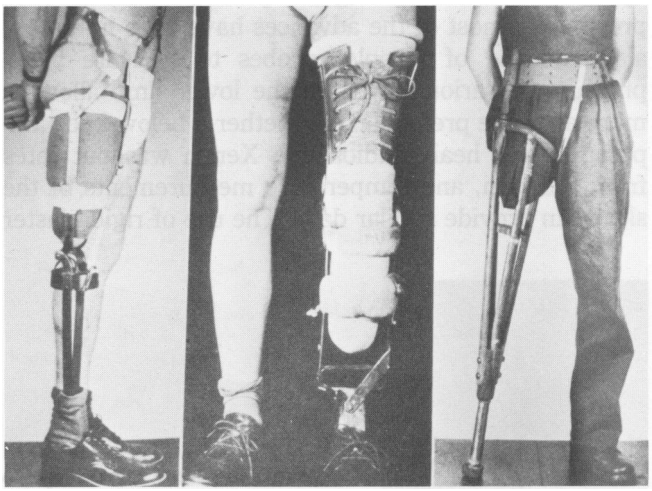

Figure 19. Homemade prostheses from World War II (Reprinted from An Atlas of Amptuations, C.V. Mosby, 1949).

this type of prosthesis because the foot of a regular below-knee prosthesis caught in the bushes.[14] The prosthesis on the right in Figure 19 was made in a Philippine prison camp from bailing wire, a crutch, a rubber hose, and a sink pipe. The two prostheses on the left were made in German prisoner-of-war camps from scrap metal.[14]

One amputation has been introduced recently. In 1939 Boyd described a modification of the Ricard am-

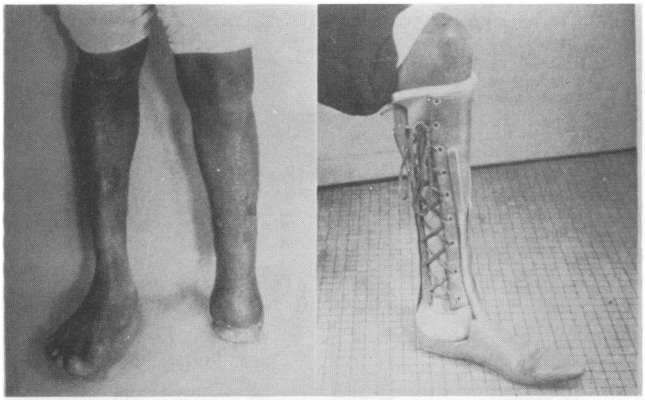

Figure 20. Boyd amputation stump and prosthesis (Reprinted from An Atlas of Amputations, C.V. Mosby, 1949).

putation in which the foot, including the talus, is excised, and the os calcis is allowed to ride in the ankle mortise. Boyd's modification involved fusion of the calcaneus to the tibia. Figure 20 shows the stump and the prosthesis. This produces a good end-bearing stump which is longer than the Syme stump.[14] One disadvantage is the need for a long plantar flap to close the incision. Also, this requires bony healing, rehabilitation is delayed, and non-union is always a possibility.

In amputations, recent advances mostly involve preoperative decision making and post operative care. In prostheses, most of the advances have been in materials. The use of Doppler probes to measure blood pressure at various levels in the lower limb allows a more accurate prediction of whether a below-knee amputation will heal. Radioactive Xenon washout rates from the skin, and temperature measurements of the skin, can provide similar data. The use of rigid plaster dressings in the immediate post-operative period of one to two weeks postoperatively, allows earlier stump shrinkage and maturation, and shorter rehabilitation time (Figure 21).

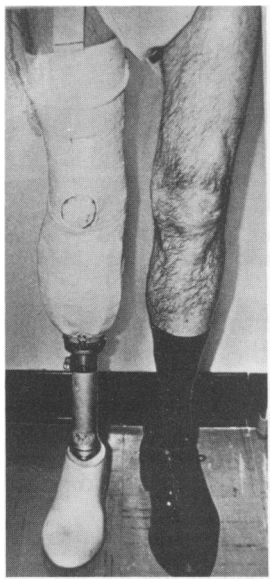

Figure 21. Below knee amputee wearing rigid dressing with pylon (Reprinted from Campbell's Operative Orthopaedics, C.V. Mosby, 1980).

The introduction of plastics for sockets, more intricate hydraulic braking mechanisms for knees, and in certain cases, myoelectric arms, have helped to improve the function of the amputee. However, one must always keep in mind Paré's patient of four hundred years ago. His circular amputation, a hands breadth below the knee joint, was done through healthy tissue, and with the use of ligatures. The soft tissues were cut more distally than the bone, providing good coverage. The patient walked in a leather and metal prosthesis with a thigh cuff and a hinged knee, and, by most accounts, functioned quite well. Obviously, we of the twentieth century have little to be smug about when we compare ourselves to our surgical ancestors. We have made some improvements, but we have changed the principles very little, and we have far to go before we can become complacent about our results in the field of lower limb amputations and prosthetics.

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